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(54) Device manufacturing method and a mask for use in the method

(57) A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using reflective patterning means (MA) to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation to form an image on a target portion of the layer of radiation-sensitive material, using a projection system (PL) that is non-telecentric on the object side;

characterized by the step of:

- shifting and/or tilting a nominal reflective surface of the patterning means (MA) away from a nominal object plane (OP) of the projection system so as to reduce distortions and/or overlay errors in the projected image.

Fig. 4A

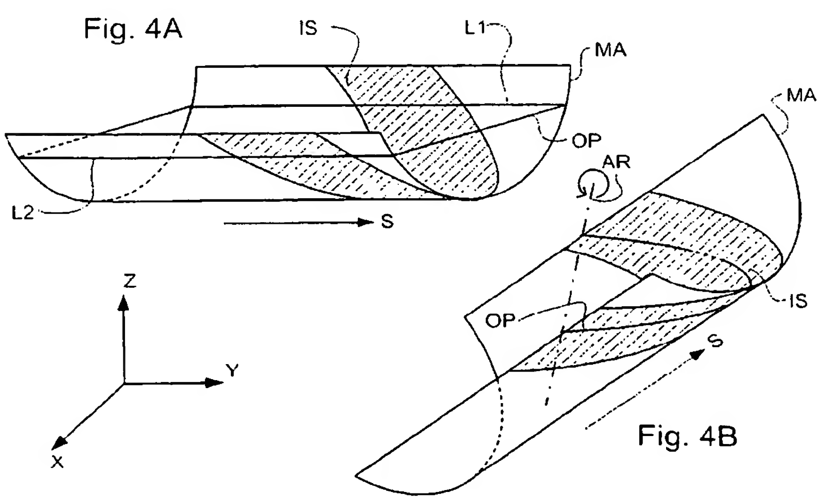

Fig. 4B

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Description

[0001] The present invention relates to a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using reflective patterning means to endow the projection beam with a pattern in its cross-section; and
- projecting the patterned beam of radiation to form an image on a target portion of the layer of radiation-sensitive material.

The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.
- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

[0002] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus— commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M

times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned. for example. from US 6.046.792. incorporated herein by reference.

[0003] In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co.. 1997, ISBN 0-07-067250-4, incorporated herein by reference.

[0004] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

[0005] In order to meet the continual demand of manufacturers of semiconductor devices to be able to produce ever smaller features, it has been proposed to use Extreme Ultraviolet (EUV) radiation, *e.g.* with a wavelength in the range of 5 to 20 nm, as the exposure radiation in a lithographic projection apparatus. Not least among the problems in designing such an apparatus is the creation of "optical" systems to illuminate evenly the patterning means and to project the image of the pattern defined by the patterning means accurately onto the substrate. Part of the difficulties in producing the necessary illumination and optical systems lies in the fact that no material suitable for making refractive optical elements at EUV wavelengths is presently known. Thus, the illumination and projection systems must be constructed out of mirrors and the mask must be reflective.

[0006] A problem associated with the use of a reflective mask is that it must be illuminated at angle, e.g. of approximately 6°, so that the projection system cannot be telecentric on the mask (object) side. Vertical (Z) displacements and tilts about horizontal axes (Rx, Ry) of the mask, e.g. caused by local deformations in the mask, cause horizontal (X & Y) displacements of the image on the substrate. Such horizontal displacements can cause overlay errors, whereby the projected image does not properly line up with previously printed process layers.

[0007] WO 01/22480 (EP 1 137 054 A1) and WO 99/45581 (EP 1 061 561 A1) disclose lithographic apparatus in which the plane of the mask is controlled to be as close as possible to the object plane of the projection system to reduce or eliminate overlay errors caused by magnification changes.

[0008] Further, previously printed layers may have become distorted in subsequent steps of the device manufacturing process. Yet further, the projection system may also introduce imaging errors giving rise to imaging and overlay errors in a printed layer. It would be advantageous to have a means to adapt to such distorted previous layers or to at least partially counteract distortions introduced by the projection system.

[0009] It is an object of the present invention to prevent or reduce imaging and/or overlay errors caused by deformations of the mask and/or distortions elsewhere in a lithographic apparatus having a projection system that is non-telecentric on the object side used in a device manufacturing method and/or to be able to adapt to or compensate for distortions introduced elsewhere in the lithographic process.

[0010] This and other objects are achieved according to the invention in a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using reflective patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation to form an image on a target portion of the layer of radiation-sensitive material, using a projection system that is non-telecentric on the object side;

characterized by the step of:

- shifting and/or tilting a nominal reflective surface of the patterning means away from a nominal object plane of the projection system so as to reduce distortions and/or overlay errors in the projected image.

[0011] Tilting and/or shifting the patterning means provides effective controllable degrees of freedom that enable the operator of the lithographic projection apparatus to introduce deliberate distortions of the projected image to compensate for or adapt to other distortions, for example errors in the projection system and distortions of the substrate, which may be caused by previous processed layers. Further, it also enables the operator to manipulate a deformed mask such that an illuminated part of the mask pattern is positioned in or at least closer to the object plane of the projection system. In particular, where the illumination field is arc-shaped and the mask has a local or global cylindrical or spherical distortion, the invention proposes that the mask be rotated so that the line of intersection between the mask and the object plane lies within the arc-shaped illumination field. With this arrangement, the scanning direction of the mask is preferably rotated by the same amount as the mask. In this way distortion of the projected image can be substantially reduced.

[0012] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0013] In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (*e.g.* with a wavelength of 365, 248, 193, 157 or 126 nm) and EUV (extreme ultra-violet radiation, *e.g.* having a wavelength in the range 5-20 nm), as well as particle beams, such as ion beams or electron beams. Also, embodiments of the invention are described in relation to an orthogonal XYZ coordinate system in which rotations about an axis *I* are denoted R_i. The X and Y axes may be described as horizontal and the Z axis as vertical but this is not to be taken as implying any necessary physical orientation of the apparatus.

[0014] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;

Figure 2 depicts the projection system of the first embodiment of the invention:

Figure 3 is a diagram illustrating how vertical displacements of the reflective mask cause horizontal displacements of the image projected by the projection system: and

Figures 4A & B are diagrams illustrating the effect of rotation of the mask;

Figure 5 is a diagram illustrating a method according to the invention of measuring the vertical position of a reflective mask having a transparent substrate;

Figure 6 is a diagram showing the position of markers used in an alternative method according to the invention for measuring the vertical position of the mask; and

Figures 7 to 12 are diagrams illustrating the effects of different deformations of the mask on the image projected on the substrate.

[0015] In the Figures, corresponding reference symbols indicate corresponding parts.

Embodiment 1

[0016] Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* EUV radiation). In this particular case, the radiation system also comprises a radiation source LA;

a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;

a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;

a projection system ("lens") PL (*e.g.* a mirror group) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

[0017] As here depicted, the apparatus is of a reflective type (*i.e.* has a reflective mask). However, in general, it may also be of a transmissive type, for example (with a transmissive mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

[0018] The source LA (*e.g.* a laser-produced or discharge plasma source) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning

means. such as a beam expander Ex. for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner. respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired intensity distribution in its cross-section.

[0019] It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus *(e.g.* with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

[0020] The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having been selectively reflected by the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

[0021] The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go *(i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;
2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner. a relatively large target portion C can be exposed. without having to compromise on resolution.

[0022] Figure 2 shows a six mirror system comprised in the projection system PL. The object side of this projection system is non-telecentric since the illumination field on the mask is shifted off-axis from the projection system and the projection beam enters the projection system PL at an angle with respect to the optical axis of the projection system. The illumination field may be arc-shaped. Further details of the projection system. and alternative projection systems, can be found in European Patent Application No 00309871.2, which document is hereby incorporated by reference. The mirrors M_1 to M_6 may be multilayer mirrors as described in European Patent Applications EP-A-1 065 532 and EP-A-1 065 568, which documents are hereby incorporated by reference.

[0023] Because the mirror system shown in Figure 2 is not telecentric on the object side, though the deviation from telecentricity is arranged to be as small as possible, local vertical (Z) deformations of the mask result in horizontal (X or Y) distortions of the image at substrate level; this is illustrated in Figure 3. In Figure 3, a vertical displacement dZ of the mask results in a horizontal displacement dx at substrate level resulting in an overall reduction in the size of the image projected on the substrate and to overlay errors. The size of the horizontal distortion is reduced because the projection system PL has a magnification of ± 1/4 or ± 1/5 but is nevertheless significant.

[0024] Figure 4A shows the mask MA having a cylindrical distortion relative to the horizontal object plane OP of the projection system PL; it will be seen that the mask MA lies in the object plane OP only along two lines L1, L2 when it is put at a position such that its mean or nominal surface is at an optimum position relative to the object plane. The illumination field IS is shown in Figure 4A by hatching. It will be seen that most of the illumination field IS lies above or below the object plane OP and will therefore be distorted. According to the invention, the mask MA is rotated so that the intersection between the mask AM and object plane OP forms an arc lying as close as possible to the center of the illumination field IS, as shown in Figure 4B. A scanning direction S is similarly rotated so that the intersection between mask MA and object plane OP remains in the center of the illumination field IS. The rotation and scanning of the mask can be performed by the first positioning means PM under appropriate software control. It should be noted that in Figures 4A and B the degree of curvature of the mask and hence the amount of rotation of it have been grossly exaggerated for illustrative purposes.

[0025] To determine the deformation of the mask, an optical sensor (such as those disclosed in European Patent Applications EP-A-1 037 117 and 01303299.0, which documents are hereby incorporated by reference) or a capacitative sensor can be used. Alternatively,

where the mask is built on a transparent substrate, a measurement may be taken from the rear, as illustrated in Figure 5. As there shown, a first measurement beam MBf is used to measure the Z position of the front surface MAf of the mask MA, on which the pattern P is provided. A second beam MBb is used to make a measurement of the Z position of the back surface MAb of the mask MA and used to correct the measurement of the Z position of the front surface MAf to remove the effect of any variation in the substrate thickness. It will be appreciated that the measurement of the mask deformation and the calculation of the necessary corrective tilt can be carried out during scanning, on-the-fly leveling, or in advance, on-axis or off-axis.

[0026] A further alternative is to use markers on the mask whose Z position can be accurately determined. Conventionally, a mask is provided with a small number of image sensor markers TISm which are used to determine the plane of best focus at substrate level and/or alignment of the mask to the substrate table. For this purpose an image sensor, for instance a transmission image sensor TIS, is provided in the substrate table and is scanned through the aerial image of the marker TISm to determine the position of the plane of best focus. According to the invention, the TIS sensor provided in the substrate table is maintained stationary and the various markers TISm projected onto it and scanned vertically to determine the position at which they are best focused onto the TIS sensor. This gives information as to the relative vertical positions of the various markers TISm. Provided a sufficient number of markers TISm is provided on the mask, the information of their vertical positions can be interpolated to give a height map of the mask. Preferably therefore, the mask is provided with a plurality of markers TISm surrounding the pattern area P, as shown in Figure 6.

[0027] A yet further alternative is to use one or more interferometers to measure the position of the top side of the mask MA as it is scanned on the mask table MT. In most cases the mask will be sufficiently reflective at a convenient wavelength that can be used in an interferometer.

[0028] For a flat reflective reticle three TISm markers (one at one side of the mask pattern and two at the other side with respect to the scan direction) would prove sufficient to determine its initial Z-position and rotation around X and Y axes, but may not provide a solution that is numerically stable. To achieve numerical stability, the number of markers is increased to six, for instance. Three markers at one side of the mask pattern and three at the other side (with respect to the scan direction) prove sufficient, also to determine a cylindrical distortion of the mask about the scan direction. More markers may prove advantageous (five at either side, for instance). To determine a cylindrical distortion along the scan direction at least one extra mark at a side of the mask pattern along the scan direction is required. More markers as shown in Figure 6 will provide better results. A numerical fit to the results (a least-squares fit, for example) will yield a mask shape to be taken into account while scanning, as described, for positioning the illuminated part of the mask in or closer to the object plane of the lens. Embodiment 1 describes a cylindrical mask distortion and on arc-shaped illumination field, but the invention may also be employed with different distortion shapes and/or illumination field of other shapes.

[0029] In a further alternative, a test mask is used. In many cases, the major contributors to mask distortions are distortions in the mask table, which will be the same for all masks used in the apparatus. Accordingly these distortions can be calibrated using a test mask with a large number of TIS markers arranged across its surface. The results obtained with the test mask can be applied directly to actual masks of similar materials and thickness but may need to be corrected for reticles of different materials or substantially different thicknesses.

Embodiment 2

[0030] In a second embodiment of the invention, which is the same as the first embodiment save as described below, the position and orientation of the mask are adjusted to compensate for distortions elsewhere in the system. Distortions that can be compensated for in this way include distortions in the projection system PL and distortions in the dies on the substrate, e.g. due to previous processing steps, for instance layers that were imaged by another lithographic projection system that has introduced some distortion.

[0031] Figures 7 to 12 illustrate the effects that may be obtained at substrate level by various movements of the mask in a scanning lithographic projection apparatus having a arc-shaped illumination field. In these Figures the arrow tails are fixed at the nominal positions of an array of points, i.e. where they would be imaged without distortion, and the arrow heads point to the positions where the points are imaged when the relevant distortion is present.

[0032] Figures 7 to 9 show respectively that translation of the mask in X or Y directions and rotation about the Z axis (Rz) result in a corresponding shift in the image at wafer level. However, a tilt around the Y-axis (the scanning axis) transforms the square array into a parallelogram array (diamond shaped distortion) and a tilt around the X-axis results in a trapezoidal array (parallelogram distortion with change in magnification in Y), as shown in Figures 10 and 11 respectively. A shift of the mask in the Z-direction results in the distortion shown in Figure 12: a change in magnification in the X-direction together with a non-uniform shift in the Y-direction. A change in magnification in the Y-direction can be obtained by varying the relative scanning speeds of the mask and substrate tables. The shift and tilt of the mask and relative speeds of the mask and substrate tables can be changed continuously during a scan.

[0033] The effect shown in Figure 11 may also be ob-

tained by a tilt of the scanning direction, rather than an actual tilt of the mask about the X axis. This effect depends upon the illuminated part of the mask being above or below the object plane to yield a reduction or magnification of the image (relative to the normal magnification) at the start of the scan and the opposite side of the object plane at the end of the scan to yield the opposite effect. Thus the effect shown in Figure 11 can be obtained by tilting the mask whilst keeping the scanning direction parallel to the object plane or by maintaining the mask parallel to the object plane and tilting the scanning direction.

[0034] Figures 10, 11 and 12 show some arc-shaped distortion, which derives from the fact that the illumination field is arc-shaped and occurs when the illuminated part of the mask is displaced from the object plane or when the ratio of the scanning speeds of the mask and substrate tables is different than the magnification ratio of the projection lens. Where such a distortion is not desirable, it may be counteracted by tilting the mask about the X axis, since the illumination field extends along the X axis. This causes the distance between the mask and object plane to differ along the illumination plane so that there will be a non-uniform shift in the XY plane along the illumination field. An appropriate choice of tilt angle can therefore result in substantially no distortion along the X-direction whilst retaining the other effects illustrated in Figures 10, 11 and 12. Also, with the mask shifted in the Z-direction to give the effect shown in Figure 12, the mask can be tilted about the X axis and the Z-shift varied so that the distance between the illuminated part of the mask and the object plane is constant. This will result in a change in magnification in X and a uniform shift in Y. Corresponding effects can be obtained by varying the relative scanning speeds of mask and substrate tables whilst tilting the mask around the X or Y axes. Varying the tilt about the Y axis while scanning yields a trapezoidal distortion orthogonal to that shown in Figure 11.

[0035] Accordingly, the ability to shift the mask in the Z-direction, to tilt it about X or Y axes and to control the relative speeds of mask and substrate tables provides controllable degrees of freedom to compensate for distortions elsewhere in the system. Such distortions may be systematic, i.e. inherent to the machine in question and static between exposures, or transient, i.e. varying between exposures.

[0036] Systematic distortions may result from errors on the projection system or deformations of the substrate table that cause deformations of the substrates mounted in them. Such distortions, and the mask shifts needed to compensate for them, may be determined during initial calibration of the apparatus and/or periodic re-calibration either by directly measuring the distortions and calculating the necessary corrections or by a trial and error process whereby a test reticle is imaged onto test substrates with different shifts and tilts.

[0037] Transient distortions may include deformations of the substrate due to previous process steps, for instance an error introduced in a previous imaging step or a substrate polishing step, or thermal distortions of elements in the projection lens. Transient distortions may be directly measured, e.g. during an alignment process for distortions of the substrate, or predicted and the appropriate shifts and/or tilts of the mask calculated in advance or immediately before the relevant exposure.

[0038] It will be appreciated that shifts in different directions and tilts about different axes can be combined to compensate for more complex distortions. For example, a non-orthogonal substrate deformation, i.e. a deformation whereby the effective X & Y axes of previous process steps are not perpendicular, may be compensated for by a combination of a translation in the X direction, a rotation about the Z-axis and a tilt about the X-axis.

[0039] The shifts and tilts of this embodiment are global in nature and thus the tilt and scanning direction of the mask are preferably made substantially constant throughout a scanning exposure.

[0040] As with the first embodiment, the necessary tilts and/or shifts of the mask may be accomplished by the positioning means PM under appropriate software control.

[0041] It will be appreciated that shifts and/or tilts of the mask to compensate for distortions elsewhere in the apparatus, as provided by the second embodiment of the invention, may be combined with shifts and/or tilts necessary to compensate for distortions of the mask, as provided by the first embodiment. Also, where a perfect compensation for distortions, whether of the mask or elsewhere, is not achievable, the present invention encompasses shifts and/or tilts of the mask to effect the best compensation practicable.

[0042] Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

Claims

1. A device manufacturing method comprising the steps of:

   - providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
   - providing a projection beam of radiation using a radiation system;
   - using reflective patterning means to endow the projection beam with a pattern in its cross-section;
   - projecting the patterned beam of radiation to form an image on a target portion of the layer of radiation-sensitive material, using a projec-

tion system that is non-telecentric on the object side;

characterized by the step of:

- shifting and/or tilting a nominal reflective surface of the patterning means away from a nominal object plane of the projection system so as to reduce distortions and/or overlay errors in the projected image.

2. A method according to claim 1 wherein said patterning means comprises a mask that has an overall curvature and said projection beam illuminates an arc-shaped region of said mask; and said step of shifting and/or tilting comprises tilting the mask such that the line of intersection between said mask and said nominal object plane is contained within said arc-shaped region.

3. A method according to claim 2 wherein said mask is scanned during said step of projecting and the direction of scanning is rotated relative to said nominal object plane by the same angle as said mask is tilted.

4. A method according to claim 1 wherein said step of shifting and/or tilting is carried out to effect a compensation for a distortion in said projection system and comprises applying at least one of the following movements to said nominal reflective surface:

   a tilt about an axis substantially parallel to said nominal reflective surface, and
   a shift in a direction substantially perpendicular to said nominal reflective surface.

5. A method according to claim 4 wherein said patterning means and said substrate are scanned during said step of projecting and said step of shifting and/or tilting comprises a tilting about an axis substantially parallel to the direction of scanning and said method further comprises the step of varying the relative speed of scanning of said patterning means and said mask table.

6. A method according to claim 1, 4 or 5 wherein said patterning means and said substrate are scanned during said step of projecting and said step of shifting and/or tilting comprises the step of tilting the scanning direction of said patterning means.

7. A method according to claim 6 wherein the tilt and the scanning direction of said patterning means are maintained substantially constant during exposure of a whole parget area.

8. A method according to claims 1, 4, 5, 6 or 7, wherein said patterning means comprises a mask held on a mask table.

9. A method according to claim 8 wherein said mask is provided with a plurality of markers surrounding a pattern area, said method comprising the step of determining the shape of said mask in said pattern area by interpolating from measurements of the position of said markers.

10. A method according to claim 8 further comprising the step of determining the shape of said mask using an interferometer to measure the position in a direction perpendicular to a nominal plane of said mask of a plurality of points on the reflective surface of said mask.

11. A method according to any one of the preceding claims wherein said projection beam is of radiation having a wavelength in the range of from 5 to 20nm.

12. A mask for use in a method according to any one of claims 1 to 11 having a plurality of markers surrounding a pattern area.

Fig. 1

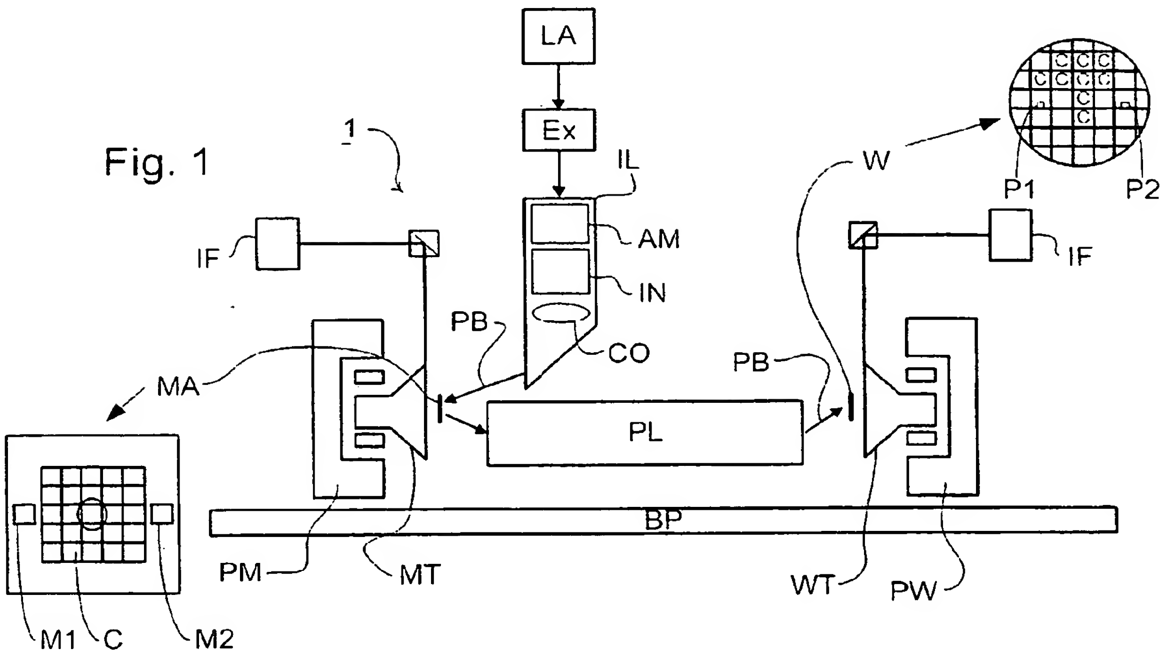
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Fig. 2

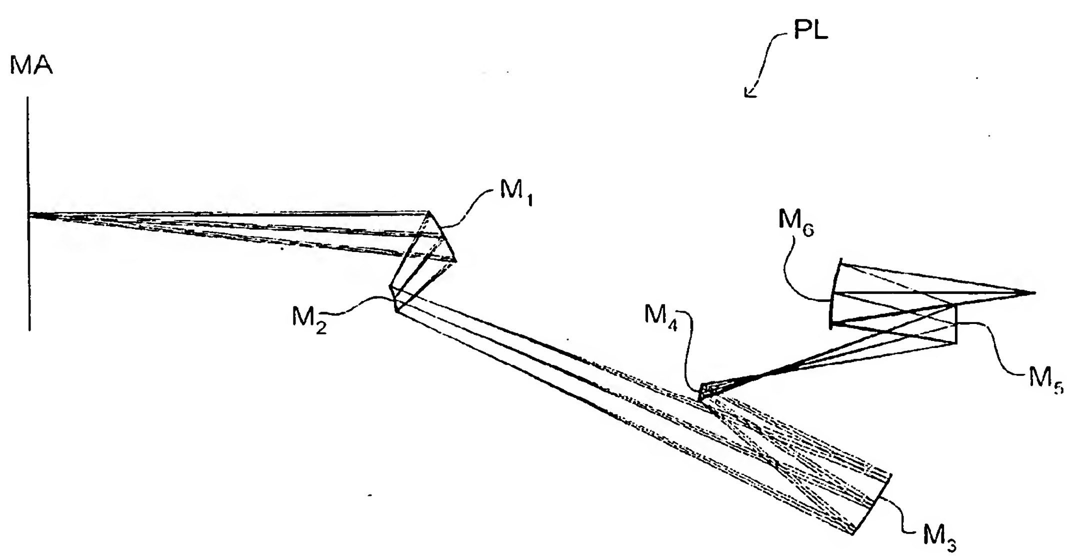
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Fig. 3

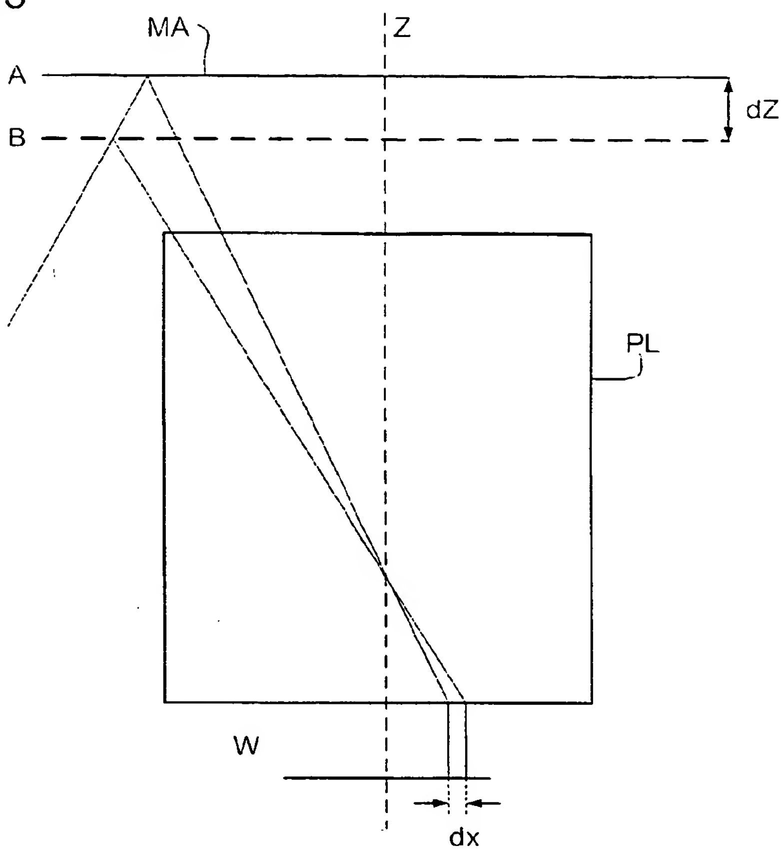


Fig. 4A

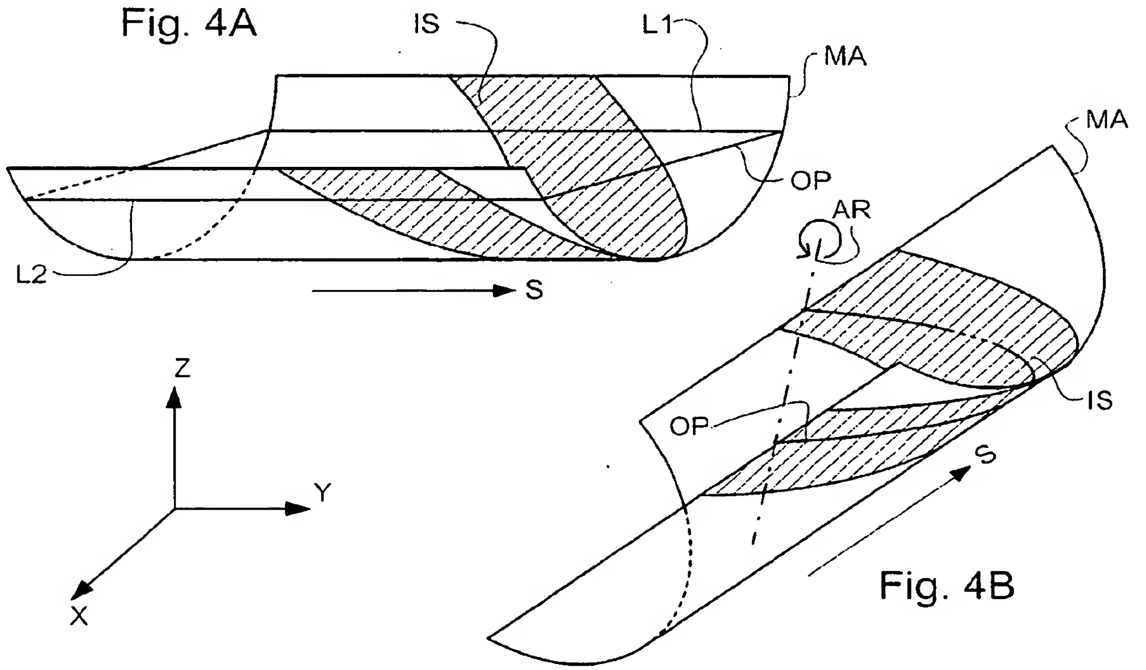


Fig. 4B

Fig. 5

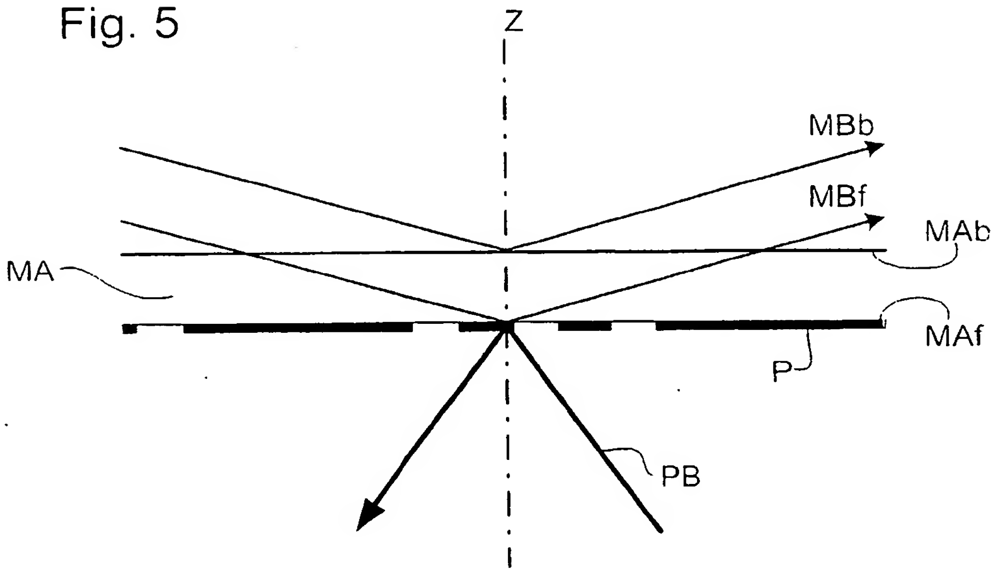


Fig. 6

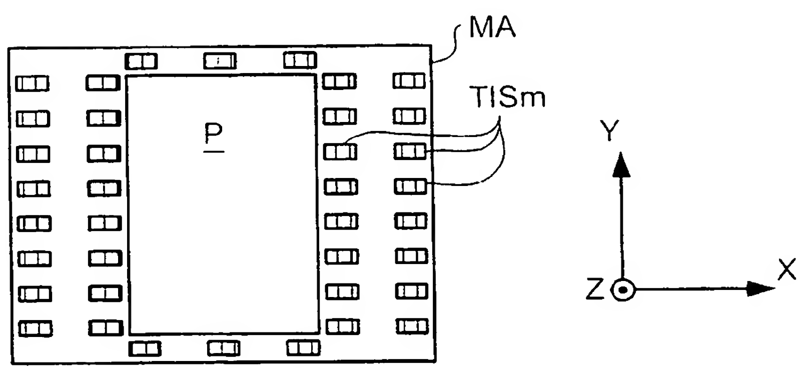


Fig. 7

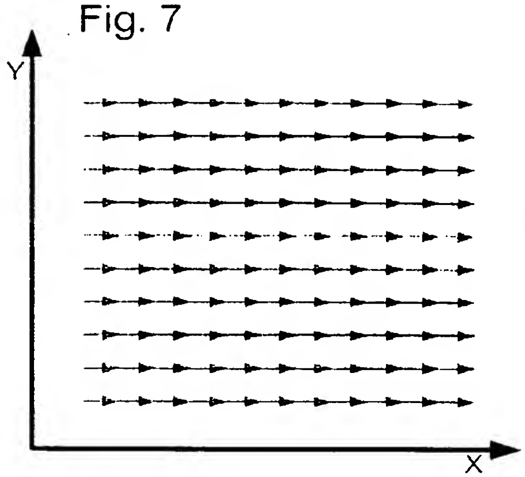


Fig. 8

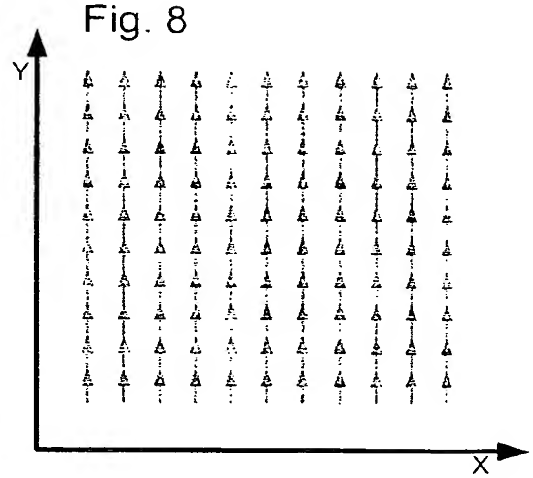


Fig. 9

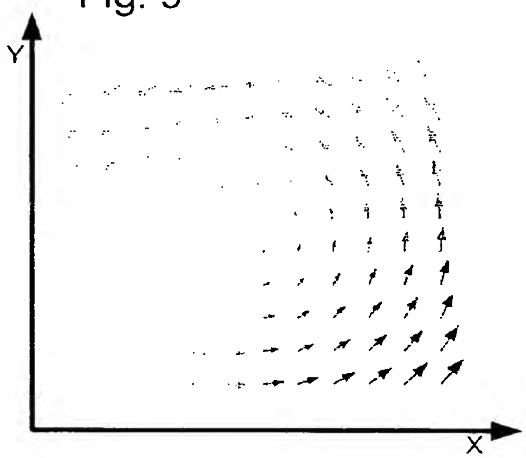


Fig.10

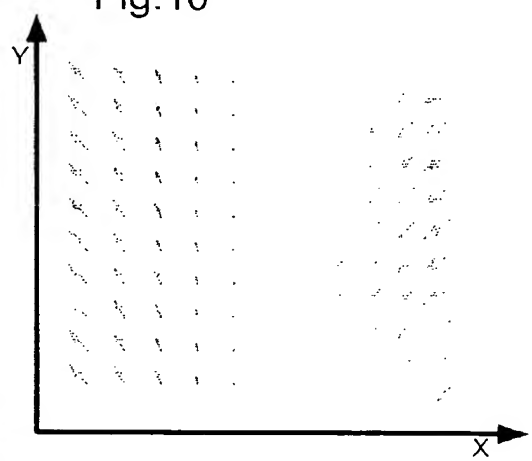


Fig. 11

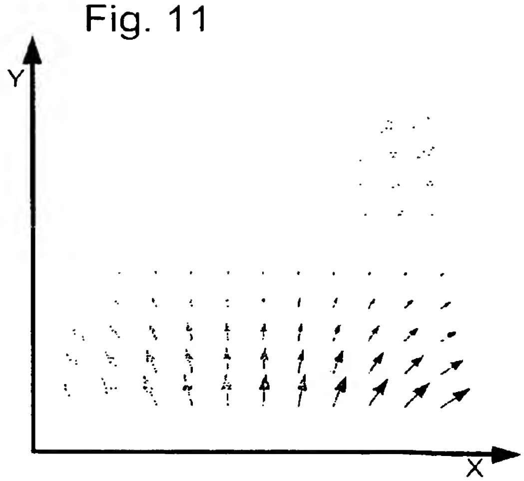
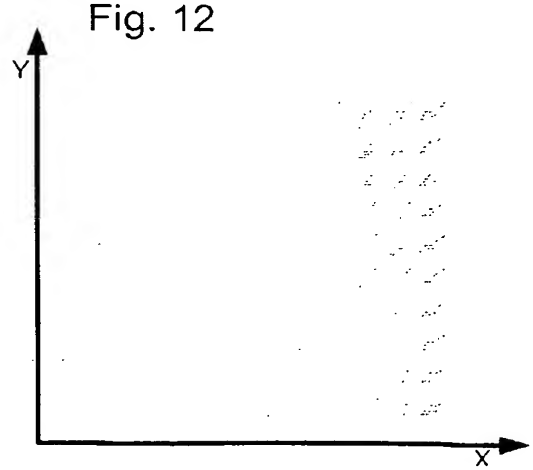


Fig. 12



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 02 25 4259

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			G03F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 September 2002	Heryet, C

CATEGORY OF CITED DOCUMENTS

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04-09-2002

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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P.D. 15-03-1999
P. 572-586 (9)

Simulation on a New Reflection Type Attenuated Phase Shifting Mask for Extreme Ultraviolet Lithography

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ABSTRACT

We have simulated the optical behavior of a new reflective APSM by utilizing the optical multilayer thin film theory. In a typical Mo/Si multilayer structure, we show that the requirement of a reflective APSM can be met simply by adjusting the thickness of the over-coated Ge layer. A phase shift of 180° results when compared light reflected from a Ge absorption layer to that from a Mo/Si multilayer, and the resultant reflectance ratio is in the range of 4 ~15 %. No additional phase shifting layer is needed.

Keywords: EUV lithography, Mo/Si multilayer mirror, reflection mask, APSM

1. INTRDUCTION

In the recent SIA roadmap, the projection lithography with extreme ultraviolet (EUV) radiation (~13 nm) may have the potential to become a manufacturing technology for dimensions less than 100 nm [1]. Attenuated phase-shifting masks (APSM's) become a vital resolution enhancement technology, and has been used widely in DUV lithography [2]. Recently a transmission type APSM has been reported to produce a better resist profile than by using a binary mask in the EUV lithography. PMMA and Ge were used as phase shifting layer and absorption layer, respectively [3]. However, it is known that a Mo/Si multilayer based reflective mask is desirable in EUV lithography as opposed to a transmission one [4]. In a multilayer based reflective mask, Ge is usually used as absorbing layer, which has fine grain size, good adhesion to the multilayer, and steep sidewall [5]. In this paper, we simulate the optical behavior of a reflective APSM by utilizing the optical multilayer thin film theory [6]. Based on a typical Mo/Si multilayer structure, we add an over-coated Ge layer to control the intensity and phase of the reflected light. A phase shift of 180° results when one compares the light reflected from a Ge absorption layer to that from a Mo/Si multilayer, and the resultant reflectance ratio is in the range of 4 ~15 %, which indicates that such a material structure may serve for a reflection type APSM.

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2. REFLECTION TYPE ATTENUATED PHASE SHIFTING MASK

In DUV lithography, the combination of both phase-shifting and attenuation functions in a single film layer is an important feature for an APSM. The optical characteristics of such a mixed film should meet the following requirements: 180° phase shift, and transmittance in the range of 4 ~15 %, all need to be measured at the operating wavelength [7]. Schematic diagrams of transmission type APSM are shown in Figure 1(a). The concept of reflection type APSM is similar to the transmission one. As shown in Figure 1 (b), a phase shift of $180 \pm 5°$ results when the light reflected from the APSM layer is compared to that from a Mo/Si multilayer reflector, and the resultant reflectance ratio is in the range of 4 ~15 %. It is also desirable to combine of both phase-shifting and attenuation functions in a single APSM layer.

3. SIMULATION RESULTS

In this paper, all simulations are calculated with the optical constants obtained from Reference 8, which has been compiled by Henke *et. al.* [8]. The EUV Mo/Si multilayer reflector has been proved to be effective in reflection working in soft x-ray wavelength radiation (~13 nm). Figure 2 (a) shows 40 layer pairs of Mo/Si with a period of 6.85 nm (41.2% Mo), which yields a peak reflectivity 75.3% at 13.4 nm for normal incidence [9]. In order to fabricate a binary reflection mask, the thickness of over-coated Ge absorber layer should be lager than 200 nm in order to obtain a large reflectance ratio between Mo/Si multilayer reflector and Ge absorber layer [5]. However, the reflection type APSM should have a reflectance ratio ranging from 4 % to 15%, and a $180 \pm 5°$ phase shift between Ge absorber layer and Mo/Si multilayer reflector. The thickness of Ge absorber layer should decrease to match such requirements. The reflection spectrum of a 37.02 nm Ge absorption layer added on the 40-pair of Mo/Si multilayer reflector is shown in Figure 2 (b). It yields a peak reflectivity of 7.13% at 13.4 nm and a 180° phase shift for normal incidence.

The dependence of reflectivity on the thickness of over-coated Ge absorption layer is shown in Figure 3. It is found the required reflectance ratio 4 % to 15% can be achieved when the thickness of Ge layer is in the range of 32.85 nm and 54.46 nm. Additionally, the dependence of phase difference between the Ge absorber layer and Mo/Si multilayer reflector on the thickness of the Ge absorption layer is shown in Figure 4. It is seen there is a periodic oscillation of phase shift with the thickness of Ge layer. Note there are several sets of Ge layer thickness, e.g. 36.99 nm - 37.18 nm, 43.74nm - 43.93 nm and 50.48 nm - 50.67 nm, that meet both requirements, i.e. phase shift $180 \pm 5°$ and reflectance ratio 4 %~15%.

The dependence of reflectivity of the 40 layer pairs Mo/Si multilayer reflector and incident angle for s-polarization at 13.4 nm is shown in Figure 5. The reflectivity decreases as the incident angle increases. The reflectivity is less than 16.8 % when the incident angle is large than 15°, which is not suitable for EUV lithography mask application.

The dependence of reflectivity on the thickness of over-coated Ge absorption layer at incident angle 5° (s-polarization, 13.4 nm) is shown in Figure 6. It is found the required reflectance ratio 4 % to 15% can be achieved when the thickness of Ge layer is in the range of 29.24 nm and 54.62 nm. Additionally, the dependence of phase difference between the Ge absorber layer and Mo/Si multilayer reflector on the thickness of the Ge absorption layer is shown in Figure 7. It is also seen there is a periodic oscillation of phase shift with the thickness of Ge layer. Note there are several sets of Ge layer thickness, e.g. 30.36 nm - 30.55 nm, 37.13 nm - 37.32 nm, 43.90 nm - 44. 09 nm and 50.67 nm - 50.86 nm, that meet both requirements, i.e. phase shift $180 \pm 5^{\circ}$ and reflectance ratio 4 %~15%.

The similar results of incident angle 10° (s-polarization, 13.4 nm) are show in Figure 8 and 9. Results indicate that the phase shift $180 \pm 5^{\circ}$ and reflectance ratio 4 %~15% can be achieve when the thickness of Ge layer are 30.68 nm - 30.87 nm, 37.52 nm - 37.71 nm, and 44.36 nm - 44.55 nm. For increasing incident angle, the reflectivity is too low to be useful in EUV lithography.

For p- polarization, similar results of the phase shift $180 \pm 5^{\circ}$ and reflectance ratio 4 %~ 15% can also be achieved with different thickness of Ge layer.

4. CONCLUSION

We have simulated the optical behavior of a new reflective type APSM for EUV lithography. In a typical Mo/Si multilayer structure, we show that the requirement of a reflective APSM can be met simply by adjusting the thickness of the over-coated Ge layer. A phase shift of 180° results when the light reflected from Ge absorption layer is compared to that from a Mo/Si multilayer, and the resultant reflectance ratio can be within the range of 4 to 15 % over some incident angles.

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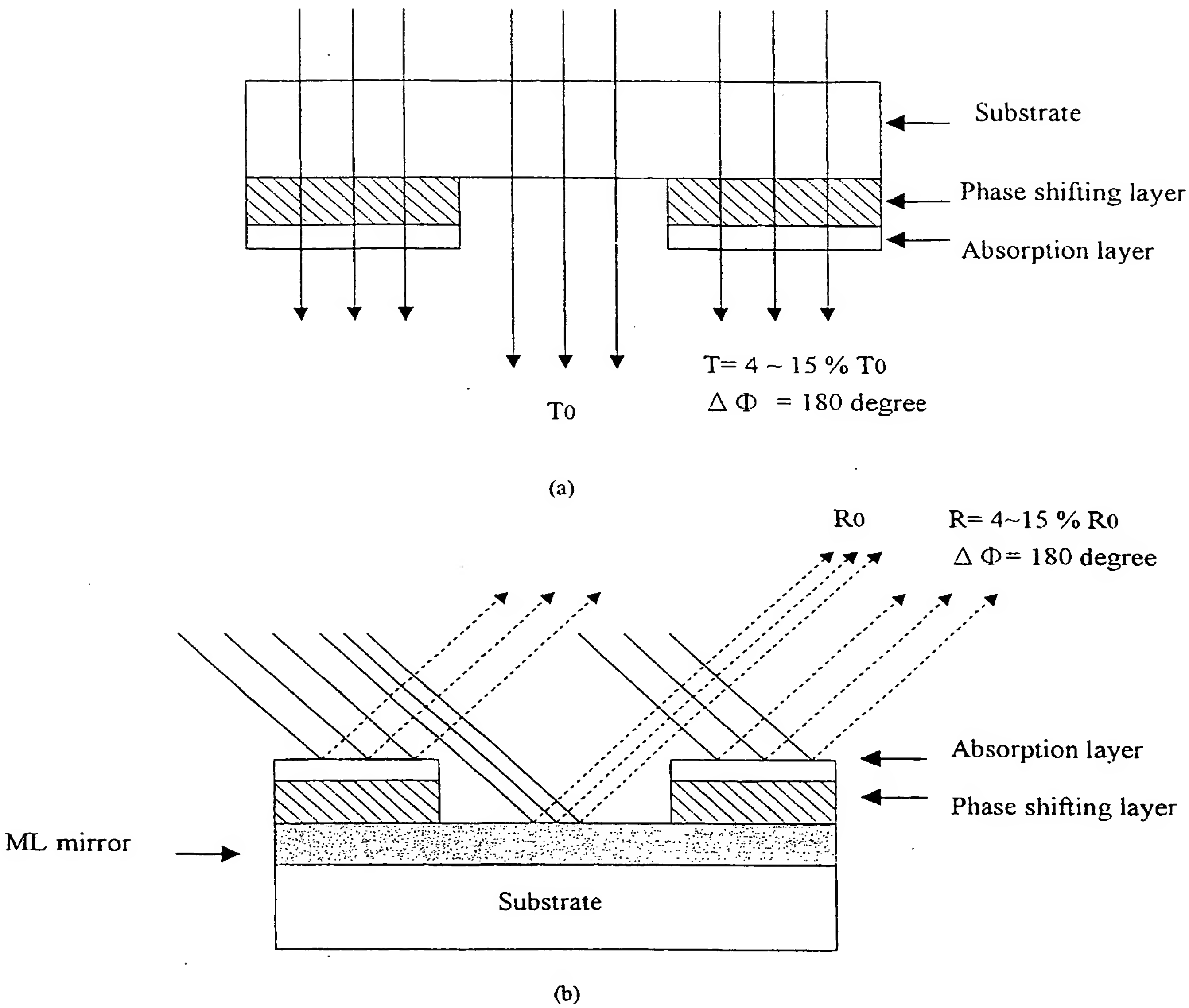
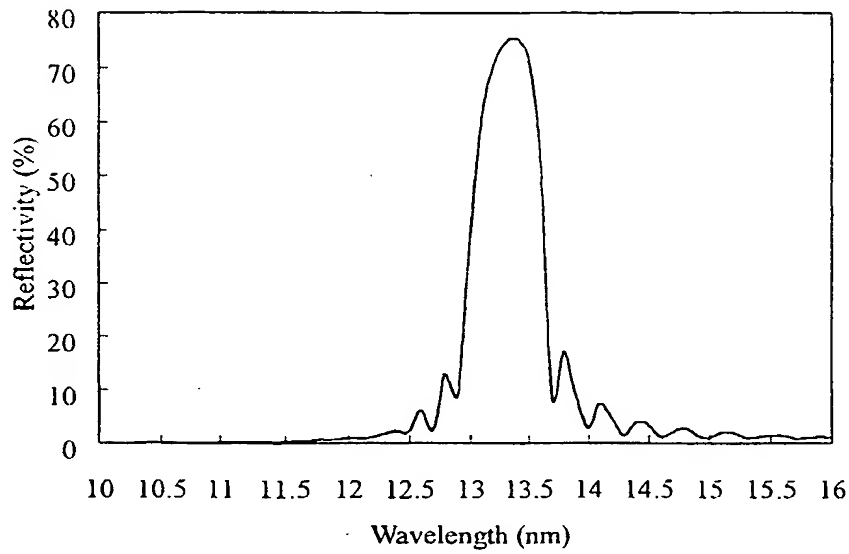
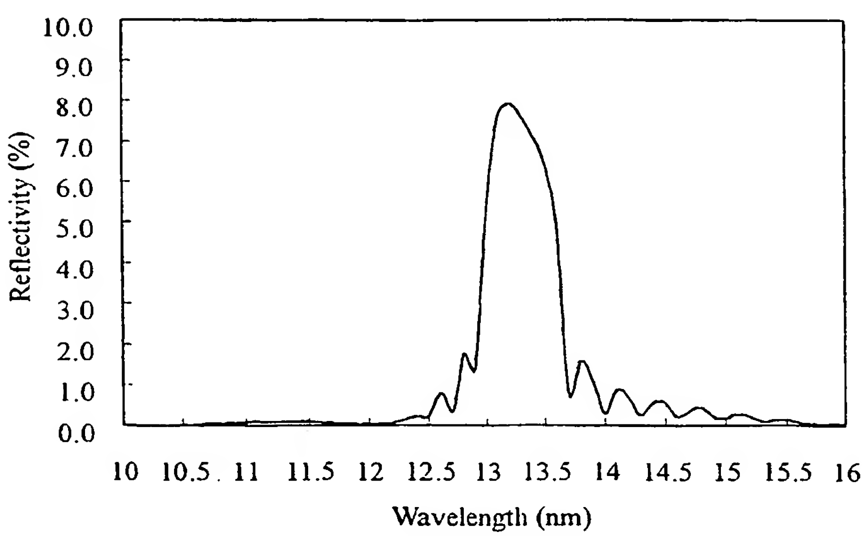


Figure 1 Schematic diagrams of (a) transmission (b) reflection type APSM's.



(a)



(b)

Figure 2 Reflection spectra of reflection type mask (a) before (b) after adding a Ge absorption layer.

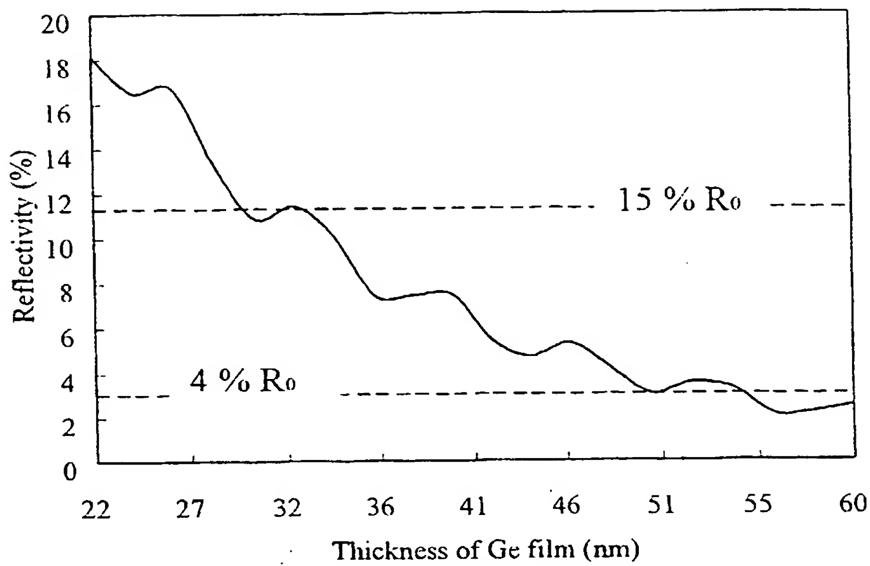


Figure 3 Dependence of reflectivity on the thickness of over-coated Ge absorption layer.

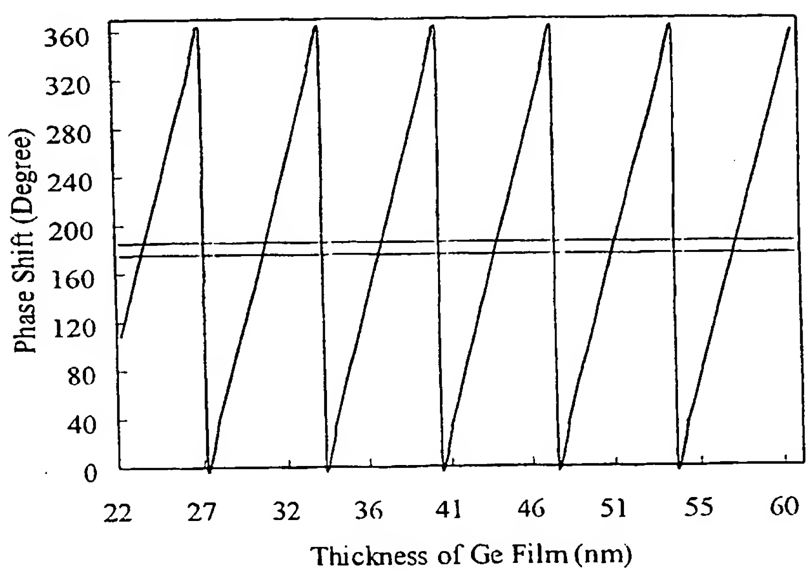


Figure 4 Dependence of phase shift on the thickness of over-coated Ge absorption layer.

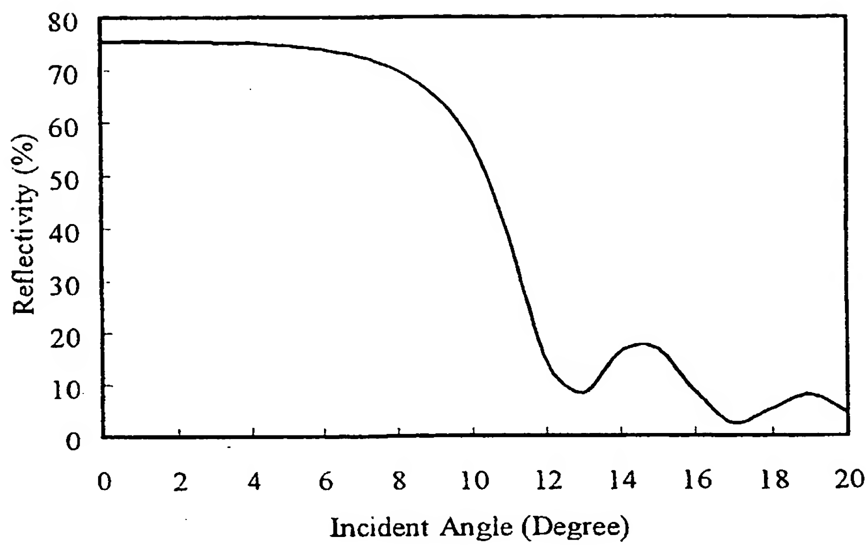


Figure 5 Dependence of reflectivity on the thickness of Ge absorption layer for s-polarization at 13.4 nm

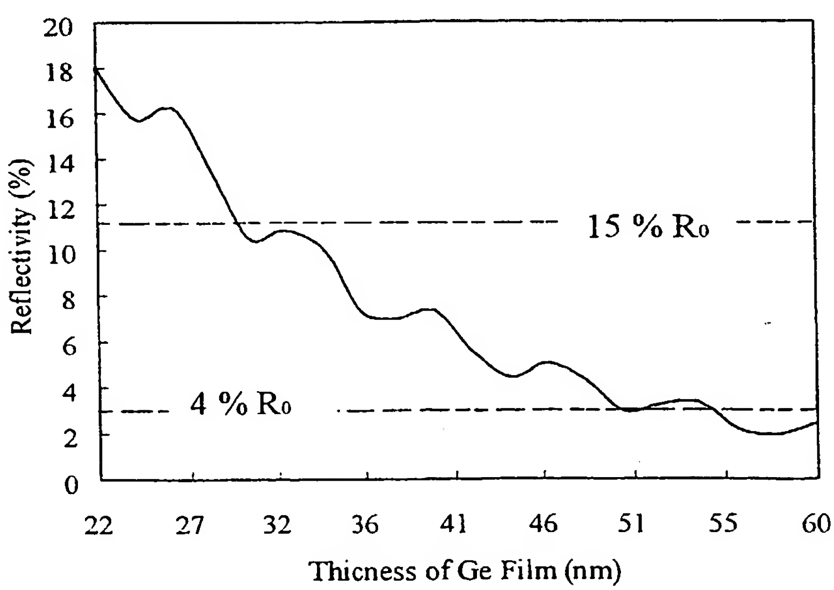


Figure 6 Dependence of reflectivity on the thickness of Ge absorption layer at 5° incident angle.

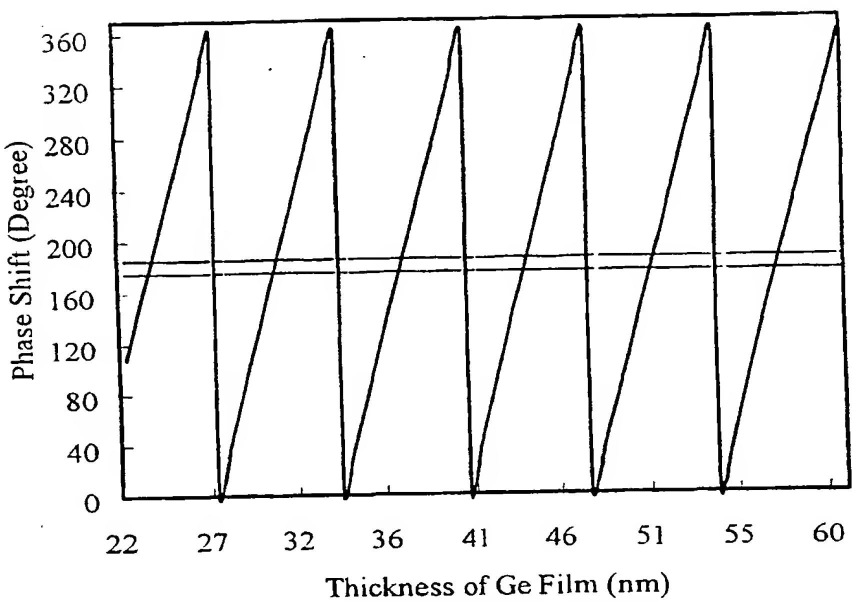


Figure 7 Dependence of phase shift on the thickness of Ge absorption layer at 5°incident angle.

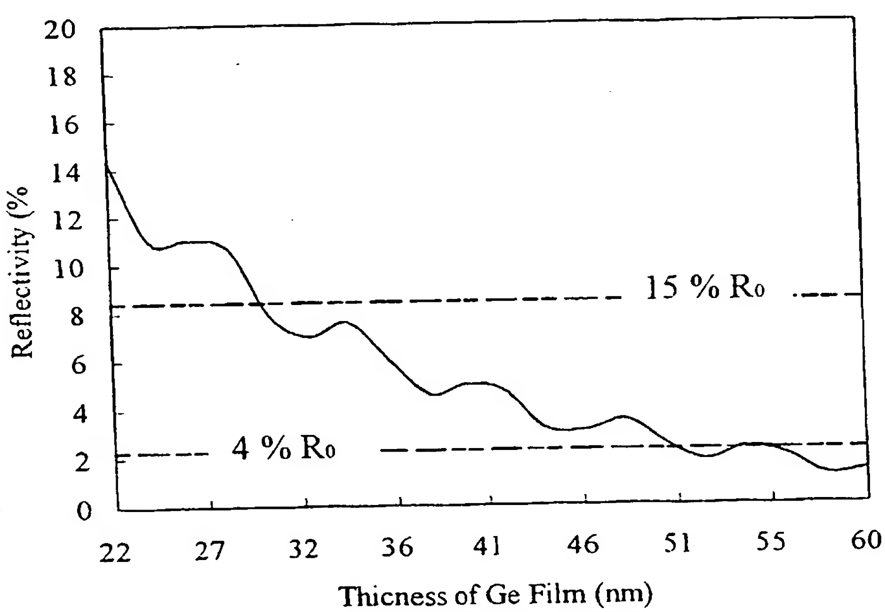


Figure 8 Dependence of reflectivity on the thickness of Ge absorption layer at 10°incident angle.

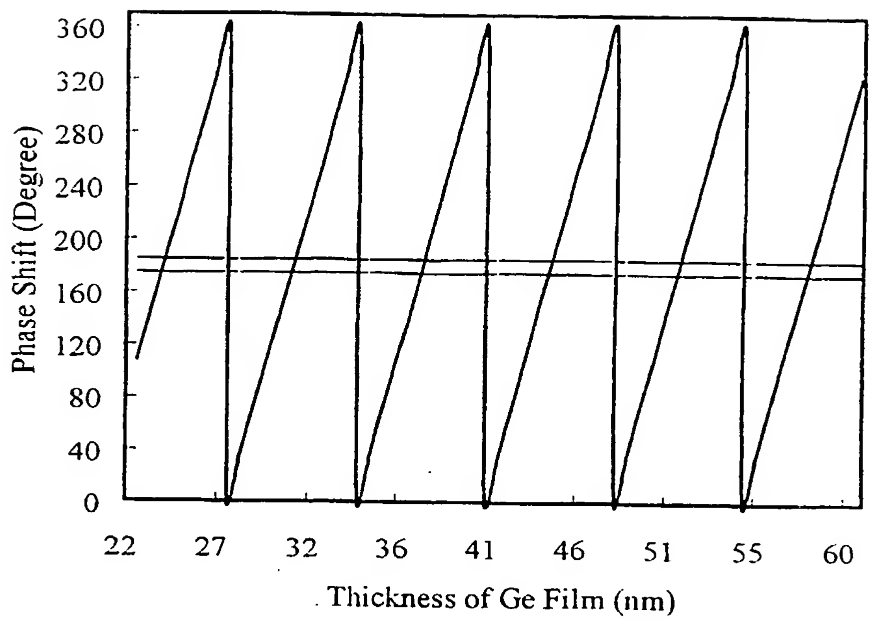


Figure 9 Dependence of phase shift on the thickness of Ge absorption layer at 10°incident angle.

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